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A New Signal Format for Efficient Data Transmisson

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I. BACKGROUND

Data communication systems in current use generally require substantially more bandwidth than the Nyquist minimum of one-half cycle per symbol. This comes about for two main reasons: first, the baseband signal spectrum has a gradual roll-off beyond the theoretical minimum;[1] second, the modulation process needed to translate the baseband spectrum to the bandpass channel generates additional side frequencies which must be preserved to permit recovery of the signal. For example, a recently described vestigial-sideband system[2] uses an extra 50 per cent of bandwidth for each of these two reasons. Consequently, such a system handles one symbol per cycle, and each symbol can convey as many levels as the signal-to-noise ratio permits — independent of all adjacent symbols. Thus, with n levels, each symbol yields $\log_2 n$ binary digits.

II. NEW TECHNIQUE

A new approach recently implemented avoids the need for excess bandwidth by using baseband shaping such that the received signal spectrum is a half-period sinusoid.[3,4] This shaping not only permits two symbols per cycle of bandwidth, but it also forces tbe baseband signal to be free of any de component. This, in turn, permits single-sideband techniques for translation to any desired frequency band without increase in bandwidth.

III. UNDERLYING PRINCIPLE

The new technique is a departure from the conventional methods which are based on zero intersymbol interference.[1] Instead, it permits intersymbol interference — but in precisely prescribed amounts. This is best illustrated by examining the impulse response for each case — or, more accurately, the end-to-end response to a single symbol (e.g., a

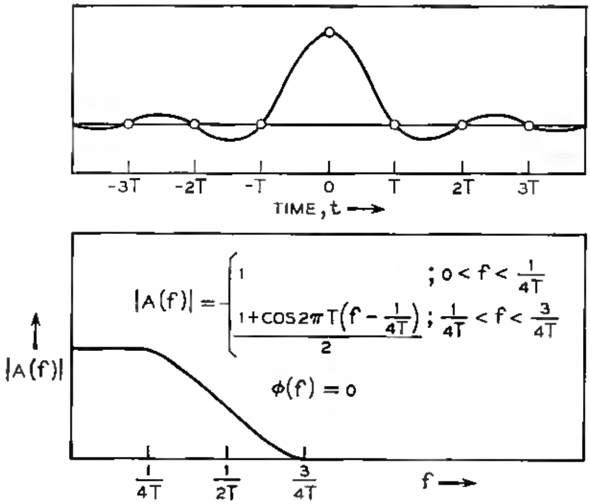

Fig. 1 — Conventional system — pulse response and frequency domain function.

"one" in a background of all zeros). Fig. 1 shows the response of a conventional system, alongside of the corresponding frequency-domain function. Fig. 2 shows the corresponding functions for the new system. In both cases, the spacing between successive symbols is T, but only in the second case is the bandwidth confined to $1/2T$.

The fact that the symbol response, as shown in Fig. 2, extends over several symbol intervals requires compensating decoding at the receiver or, advantageously, precoding at the transmitter[3] similar to "duobinary"

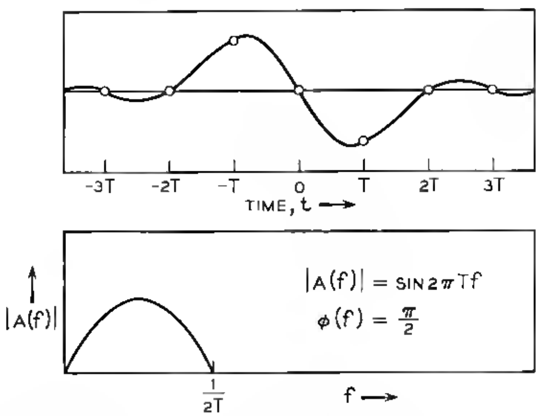

Fig. 2 — Partial response system — pulse response and frequency domain function.

or "biternary" coding.[4,5] Performance with either method is comparable to that achieved with other three-level systems.[6] The precoding used in the present implementation converts the original binary data sequence $a_1, a_2 \cdots a_n$ into a new binary sequence $b_1, b_2 \cdots b_n$, which the channel converts into the received three-level sequence $c_1, c_2 \cdots c_n$. The following relations hold

$$c_n = b_n - b_{n-2} \tag{1}$$

(by definition of the system response)

$$a_n \equiv [b_n + b_{n-2}] \bmod 2 \tag{2}$$

(by design of the precoder).

It follows that $a_n = [c_n] \bmod 2$, which means odd and even-numbered levels of c_n signify $a_n = 1$ and zero, respectively, the same as with biternary/duobinary encoding. The precoding relation (2) is implemented with a mod-2 adder and a shift register (see Fig. 3).

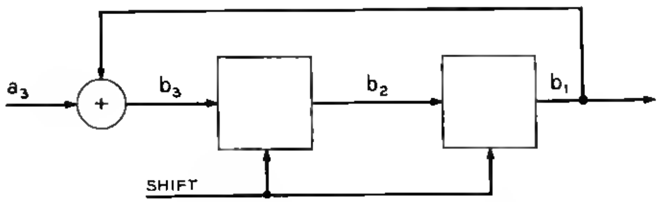

Fig. 3 — Transmitter precoding system.

IV. MODULATION PROCESS

Of all the known methods for translating a signal into a desired frequency band only single-sideband transmission preserves the signal bandwidth. This is illustrated in Fig. 4; the numbers correspond to an experimental *Data-Phone** set presently being tested on the switched telephone network at 2400 bits/sec.

In this instance the transmitted spectrum covers exactly one octave. It is generated by simply sampling the data and selecting the desired spectral band with a filter approximating the square root of the half-sinusoidal characteristic $H(f)$. A matching filter at the receiver then completes the shaping shown in Fig. 4. The carrier pilot is transmitted outside of these filters; it is recovered through a narrow-band filter (just wide enough to preserve any multiplicative noise imparted by the

* *Data-Phone* is a service mark of the Bell System.

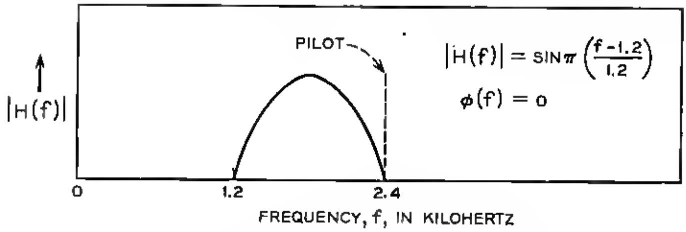

Fig. 4 — Partial response spectrum for single-sideband transmission.

channel). Tbe carrier phase is rotated by 90 degrees before it is used for demodulation, corresponding to odd symmetry of $h(t)$ (see Fig. 2).

V. EQUALIZATION

Extensive computer simulation has shown tbat the system can tolerate substantial amplitude and phase distortion of various shapes. Since this tolerance is obtained at the expense of noise margin, it proved desirable to incorporate a limited amount of automatic equalization[7] for operation on the switched telephone network. This has been accomplished by formulating a new algorithm for automatic equilization of partial-response signaling formats.[8]

VI. SUMMARY

A data terminal incorporating the above principles has successfully performed in preliminary tests over a variety of cross-country dialed telephone connections. The data rate was 2400 bits/sec. In addition, a 150 bit/sec channel was operated in the reverse direction in the band below 1000 c/s. Details concerning design and performance will be published after evaluation is complete.

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